AIR CONDITIONING AND PSYCHROMETRY

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AIR CONDITIONING

The term air conditioning means treating of air or conditioning the air to change its temperature or the moisture as per the requirements of various applications. Air conditioners are used throughout the world for a number of applications and one just can't imagine the life without them. They are the devices or machine that condition or alter the state of the air by changing its temperature and the humidity level. Though you may have read about the various types of air conditioning systems, you may have hardly bothered about reading the various constituents of the air and what changes occur in them that lead to reduction in the temperature of the air and changes in its humidity (Bright Hub Engineering, 2009).

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PSYCHROMETRY

Psychrometry is the science of study of various properties of air, method of controlling its temperature and moisture content or humidity and its effect on various materials and human beings. Studying Psychrometry helps understanding different constituents of air and how they affect each other, which in turn unravels various mysteries of the atmosphere and the nature. Some of the psychrometric properties of air that we are going to study are: dry bulb temperature, wet bulb temperature, dew point temperature, relative humidity (Bright Hub Engineering, 2009).

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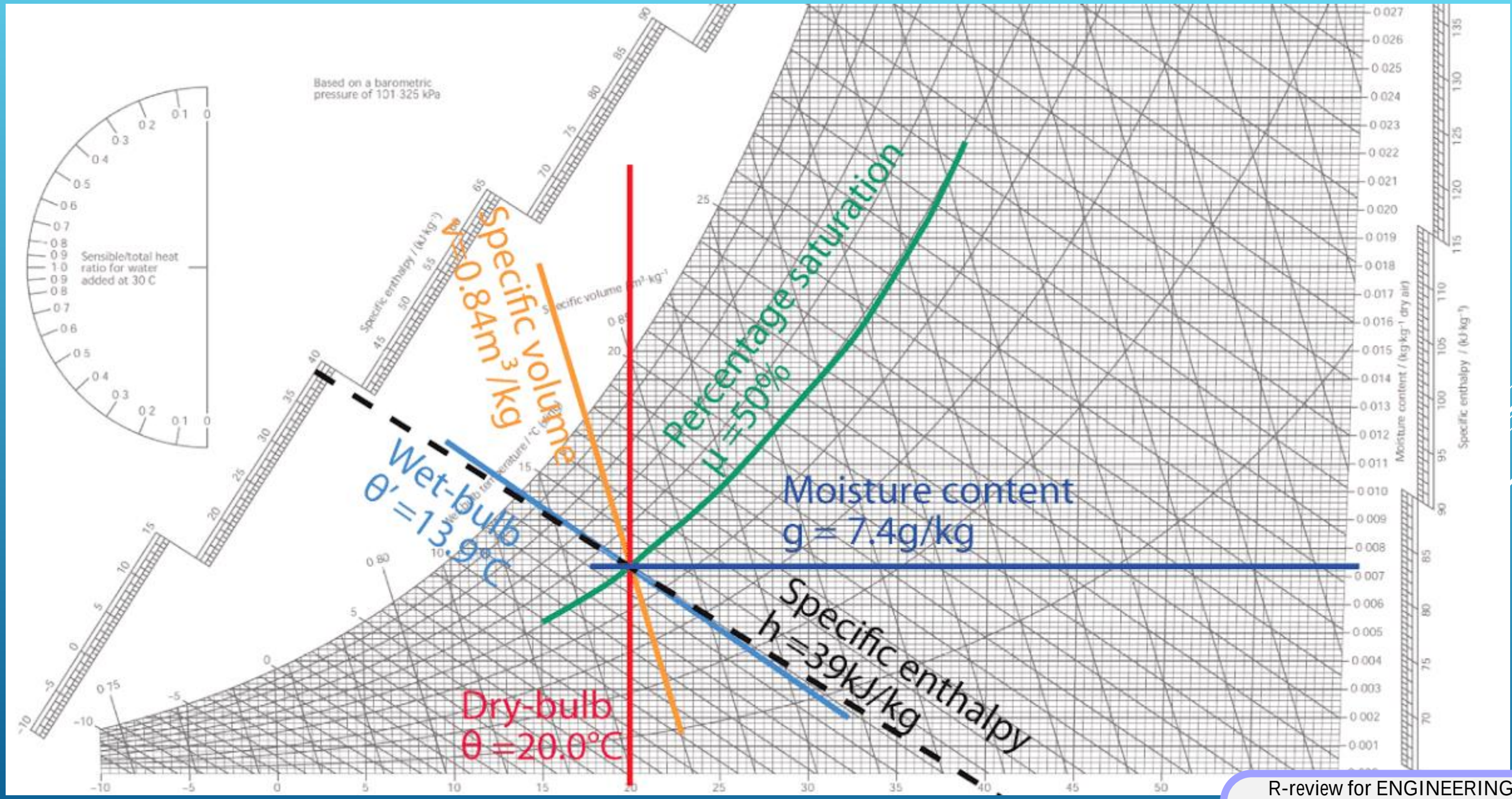

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- 1. Atmospheric or Barometric Pressure
- From Dalton's Law of Partial Pressures, states that this moist or humid air exerts an atmospheric pressure of:
  - $P_{atm} = P_B = P_a + P_v$ kPa
  - Where:
  - $P_{atm} = P_B$ = atmospheric or barometric pressure
  - P_a = Partial Pressure of Dry Air
  - $P_a = m_a R_a T_a / V_a$
  - $R_a = 0.287\ kJ/kg_a - K$
  - P_v = Partial Pressure of Water Vapor
  - $P_v = m_v R_v T_v / V_v$
  - $R_v = 0.4615\ kJ/kg_v - K$
  -

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- From Dr. Carrier's Equation:
- Eng'g units
- $P_v = P_{sw} - (P_B - P_{sw})(t_d - t_w)/(2830 - 1.44t)$,psi
- SI units
- $= P_{sw} - (P_B - P_{sw})(t_d - t_w)/(1500 - 1.4t_w)$,kpa
- P_V
- Where:
- P_{sw} = saturation pressure at t_w
- t_w = wet-bulb temperature
- t_d = dry-bulb temperature

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- **TEMPERATURES:**
  - **(a)Dry-bulb temperature, t_d**
  - Dry-bulb temperature is the actual temperature using an ordinary thermometer.
  - **(b) Wet-bulb temperature, t_w**
  - Wet-bulb temperature is the temperature measured using an ordinary thermometer where the bulb is enclose in wick or cloth that is kept moistened.
  - **(c) Dew point temperature, t_{dp}**
  - Dew point temperature is the temperature where the water vapor content of moist or humid air becomes saturated and ant further cooling will cause condensation.

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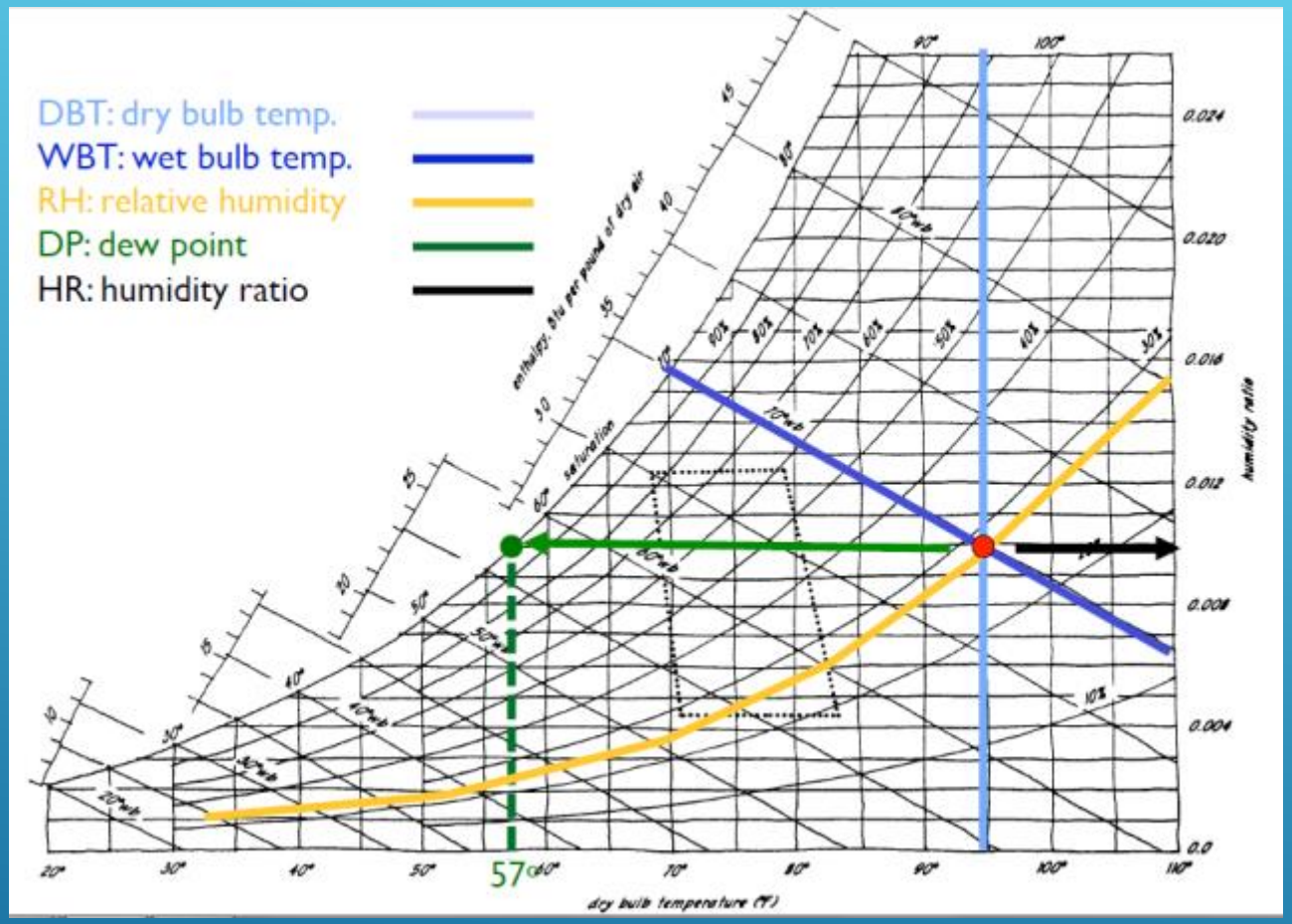

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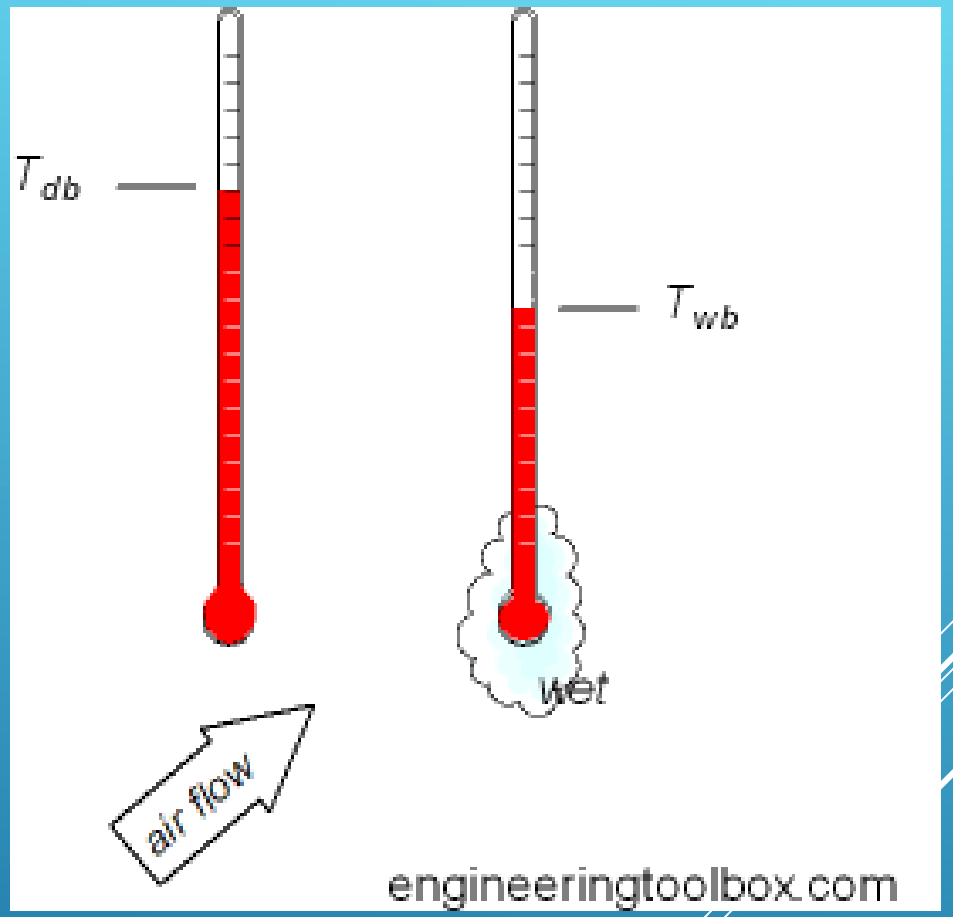

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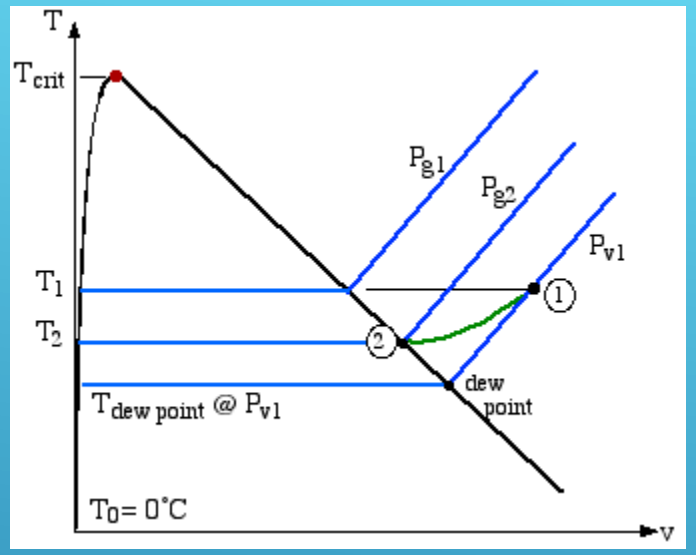

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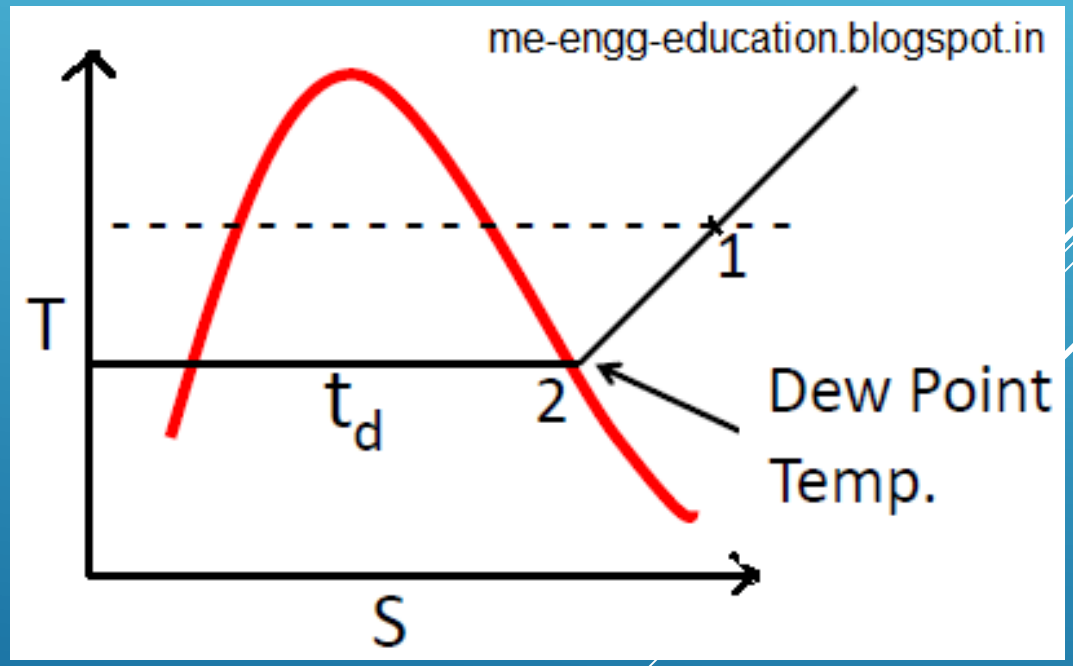

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- 2. Humidity
- Is defined as the amount of moisture or water vapor in the air.
- a. Humidity Ratio or Specific Humidity
- Is defined as the ratio of the mass of water vapor to the mass of dry air.
- $SH = m_v/m_a$ kg_v/kg_a or lb_v/lb_a
- For dry air:
- $m_a = \frac{P_a V_a}{R_a T_a}$
- For water vapor:
- $M_v = \frac{P_v V_v}{R_v T_v}$
- Substituting;
- $SH = \frac{\frac{P_v V_v}{R_v T_v}}{\frac{Pava}{R_a T_a}}$; since $V_a = V_v$ and $T_a = T_v$
- $SH = \frac{Ra}{R_v}\left[\frac{P_v}{P_a}\right]$
- Where: $R_a = 0.287$ kJ/kg_a-K
- $R_v = 0.4615$ kJ/kg_a-K
- $P_B = P_a + P_v$
- $SH = 0.622\left[\frac{P_v}{P_{B\_Pv}}\right]$
-

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- b. Relative Humidity
- Is defined as the ratio of the partial pressure of water vapor to that of saturated vapor pressure at a given dry bulb temperature, expressed in percentage.

- Where : P_{sd}= saturation pressure of water vapor at dry bulb temperature

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- c. Absolute Humidity – Is defined as the amount of water vapor present in a unit volume of air, expressed in kilograms per cubic meter.
- $H_{abs} = m_v/v_m$, kg_v/m_m^3 note: $V_m=V_a=V_v$
-
- For dry air, V_a:
- $$V_a = \frac{m_a R_{aTa}}{P_a}$$
- $$H_{abs} = \frac{mv}{\frac{maRaTa}{P_a}}$$
-
- $$H_{abs} = SH \left[\frac{P_a}{R_{aTa}}\right]$$
-
- For water vapor, V_v:
- $$H_{abs} = \frac{mv}{V_v} = \rho_v$$

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3. Specific Volume of dry air

$$P_aV_a = m_aR_aT_a$$

$$v_a = v_am_a = \frac{R_{aTa}}{P_a}, \ m_a^3/kg_a$$

4. Saturation Ratio or Degree of Saturation

Is defined as the ratio of the actual specific humidity to the specific humidity of saturated air at the same dry bulb temperature.

$$\emptyset = SH_a/SH_s$$

$$\emptyset = \frac{0.622\left[\frac{P_v}{P_B - Pv}\right]}{0.622\left(\frac{P_{sd}}{P_B - Psd}\right)} * 100\%$$

$$\emptyset = \frac{Pv}{Psd}\left[\frac{P_B - P_{sd}}{P_B - Pv}\right] * 100\%$$

$$\emptyset = RH\left[\frac{P_B - Psd}{P_B - Pv}\right] * 100\%$$

where: P_{sd}= saturation pressure at t_d

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5. Enthalpy of Moist or Humid Air

Is defined as the sum of enthalpy of the dry air and the enthalpy of water vapor.

$H_M=H_a+H_v$, kJ

$[H_M=m_a h_a+m_v h_v]\ 1/m_a$

$H_M /m_a= h_a+m_v/m_a\ (h_v)$

$h = h_a+ SH(h_v)$, kJ_M/kg_a

where: $h_a= Cp_a(t_d-0)$

$h_a= Cp_a t_d$

$h_v= h_g$ at dry bulb temperature, t_d

Using steam tables

If steam table is not available, use:

$h_v = 2501.3 + 1.82\ (t_d)$, kJ/kg_v

Maximum error of 1.9 kJ/kg_v

over the temperature range of -20°C and 100°C.

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Example 11-1.:

Air at atmospheric pressure of 101.325 kPa and with dry-bulb and wet-bulb temperature of 25℃ and 20℃ , respectively, flows in a round duct of diameter 850 mm with a velocity of 8 m/s. Determine:

(a) Relative Humidity, RH

(b) Humidity Ratio, SH

(c) Specific Volume of dry air

(d) The Dew Point temperature, t_{dp}

(e) Enthalpy, h

(f) The Mass Flow Rate of dry air, m_a

(g) The Mass Flow Rate of water vapor, m_v

(h) The Mass Flow Rate of moist air, m_M

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SOLUTION:

For RH;

$$RH = \frac{Pv}{P_{sd}} * 100\%$$

$$P_v = P_{sw} - \frac{(PB - Psw)(td - tw)}{(1500 - 1.4tw)}$$

$P_{sw} = P_{sat} @ t_w = 20°C = 2.399$ kPa

$$P_v = (2.399\ kPa) - \frac{(101.325)kPa(25-20)°C}{(1500 - 1.4tw)(20°C)}$$

$P_v = 2.0026$ kPa

$P_{sd} = P_{sat} @ t_d = 25°C = 3.169$ kPa

$$RH = \frac{2.0026\ kPa}{3.169\ kPa} * 100\%$$

RH = 63.2%

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For v;

$$v=\frac{R_3 T_3}{P_B - PV}=\frac{\left(0.287\frac{kJ}{kg_a - K}\right)(25+273)K}{(101.325-2.0026)kPa}$$

$$\mathbf{va= 0.8611\frac{m^3}{kg_a}}$$

For t_{dp}

t_{dp} = t at P_v = 2.0026 kPa (by interpolation, using steam tables)

$$\mathbf{t_{dp}= 17.5165\ ^0C}$$

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For H;

$$h = h_a + SH(h_v)$$

$$h_a = Cp_a t_4 = (1.0062 \frac{kj}{kg_a - K})(25)K = 25.155 \frac{kJ}{kg_a}$$

$$h_v = h_{g,} \text{ at } t_d = 25^oC = 2547.2 \frac{kJ}{kg_v}$$

$$h = 25.155 \frac{kJ}{kg_a} + 0.01254 \frac{kg_v}{kga} (2547.2 \frac{kJ}{kg_v})$$

$$\mathbf{h = 57.0969 \frac{kJ}{kg_a}}$$

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For m_M ;

$$m_M = m_a + m_v$$

$$m_M = m_a + SHm_a$$

$$m_M = (5.2719\frac{kg_a}{s}) + (0.06622\frac{kg_v}{s})$$

$$\mathbf{m_M = 5.3880\frac{kg_M}{s}}$$

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THE PSYCHROMETRIC CHART

A psychrometric chart is a graph of the physical property of moist air at a constant pressure (usually at sea level). Note that if the atmospheric pressure is significantly different from standard pressure, the equation present must be used.

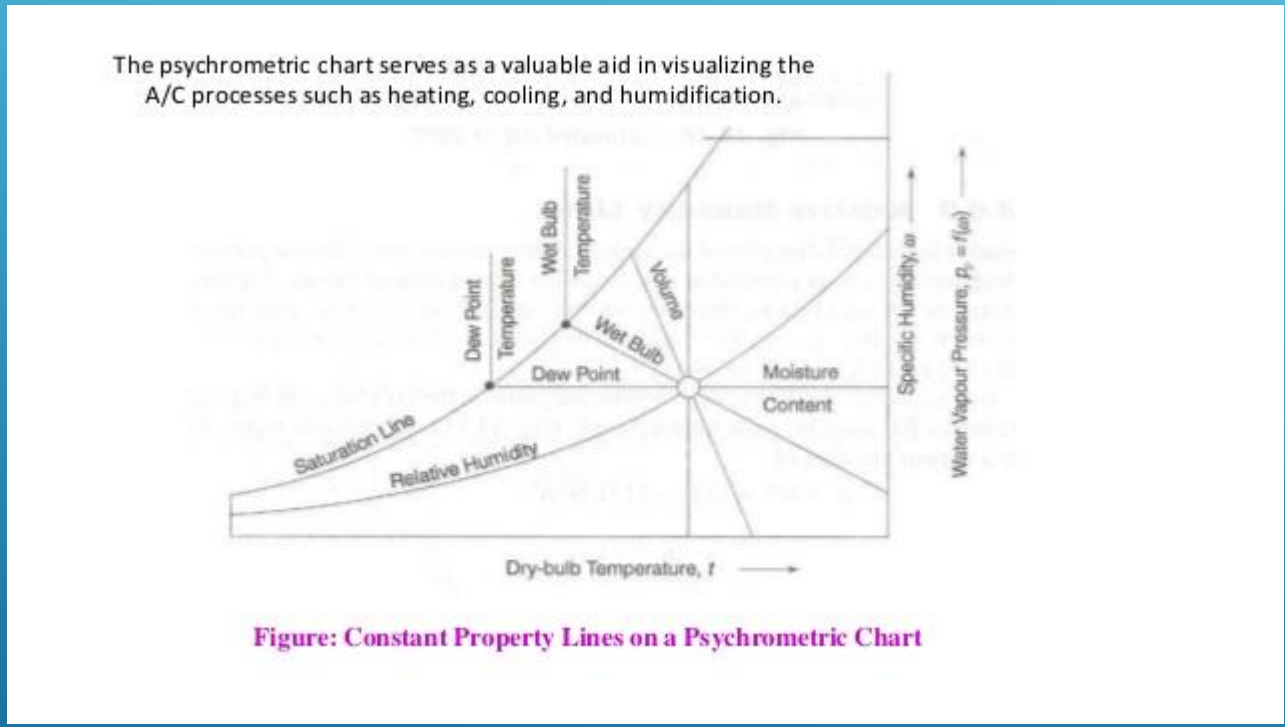

Figure: Constant Property Lines on a Psychrometric Chart

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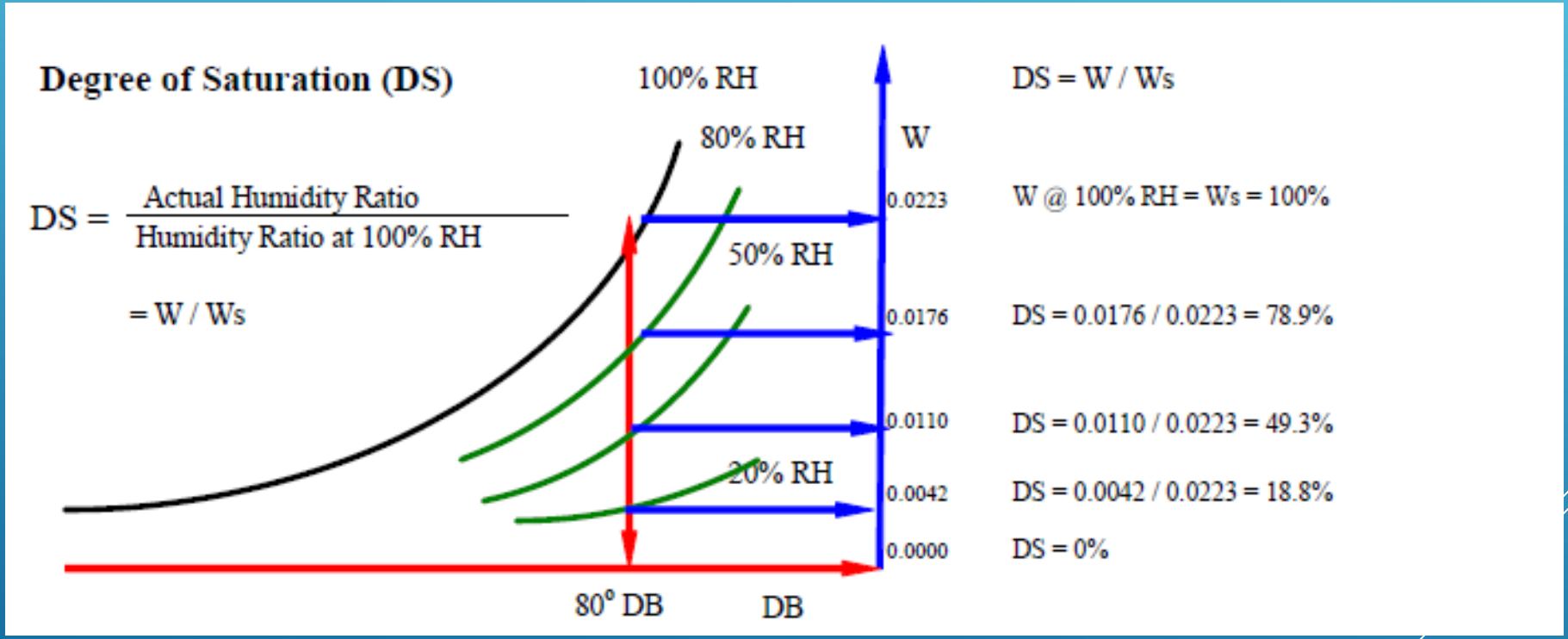
DEGREE OF SATURATION

Degree of saturation: The humidity ratio of water vapour in a sample divided by the humidity ratio of water vapour in saturated air at the same temperature and pressure. Humidity ratio: The humidity ratio is the mass of water vapour divided by the mass of dry air in a sample.



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Example11-2;

Air at atmospheric pressure of 101.325kPa, dry bulb temperature of 25ºC ad wet bulb temperature of 20ºC. Using psychrometric chart, determine;

(a) Relative Humidity, RH

(b) Humidity Ratio, SH

(c) Specific Volume of dry air, v_a

(d) The Dew Point Temperature, t_{dp}

(e) Enthalpy, h

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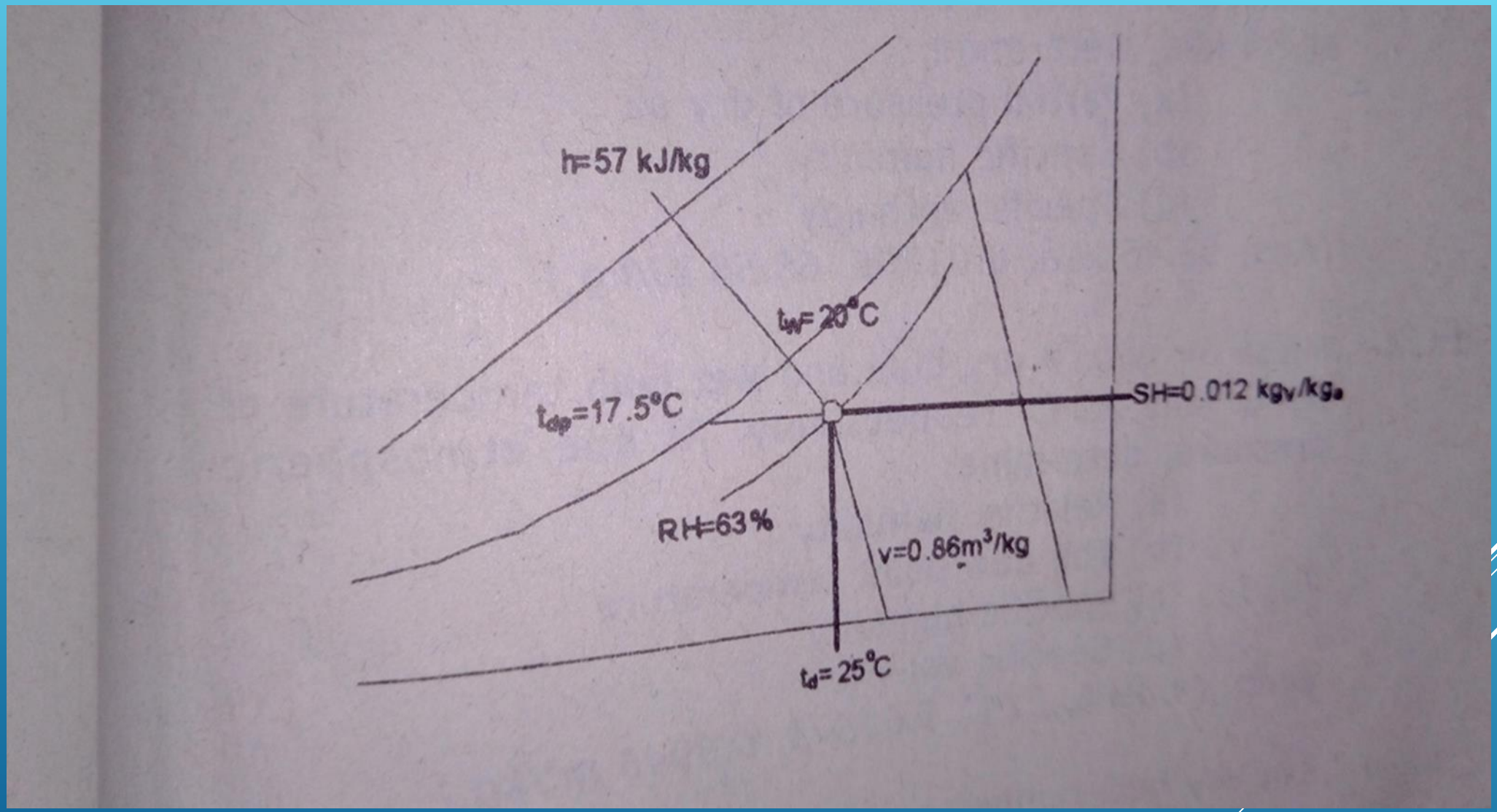

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SUGGESTED READINGS and EDUCATIONAL VIDEOS

1. https://www.brighthubengineering.com/hvac/39506-what-is-psychrometry-composition-of-air/
2. https://www.sciencedirect.com/topics/engineering/psychrometrics
3. https://nptel.ac.in/content/storage2/courses/112105129/pdf/R&AC%20Lecture%2027.pdf
4. https://www.youtube.com/watch?v=gVLhrLTF878
5. https://www.youtube.com/watch?v=D66uqsKURs4

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PROBLEM SET:

11.1 Moist air with a dry bulb temperature of 27ºC and a dew point temperature of 10ºC at a pressure of 1 atm.

Determine:

(a) Relative Humidity

(b) Specific Humidity

(c) Specific Enthalpy

(d) Degree of Saturation

(e) Specific Volume of Dry Air

(Ans. 50.97%, 0.01336, 56.5kJ/kg$_a$, 50%, 0.8653m^3)

11.2 Moist air has dry bulb temperature of 25ºC and a relative humidity of 80%. If the barometric pressure is at 95kPa, Determine:

(a) Partial Pressure of dry air

(b) Specific Humidity

(c) Specific Enthalpy

(Ans. 92.46 kPa, 0.01705, 68.58 kJ/kg$_a$)

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11.3 Moist air with a dry bulb and wet bulb temperature of 35°C and 25°C, respectively. At one atmospheric pressure, determine:

(a) Relative humidity

(b) The dew point temperature

(c) Specific humidity

(d) Specific Volume

(Ans. 44.39%, 21%C, 0.01573, 0.8949 m^3/kg_a)

11.4 The dry bulb temperature of moist or humid air is 21°C and 50% relative humidity. If the volume of air is 130 m^3 at an atmospheric pressure of 98 kPa, determine:

(a) The specific humidity

(b) The temperature where the water vapor starts to condense.

(C) The mass of water vapor

(Ans. 0.007994, 10.18°C, 1.1916 kg)

11.5 Moist air has a dry bulb and wet bulb temperature of 32°C and 28°C, respectively. If the relative humidity is 45%, determine:

(a) Specific humidity

(b) The dew point temperature

(c) Specific Enthalpy

(Ans. 0.01343, 18.58°C, 66.57 kJ/kg_a)

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